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Response of southwest Yukon forests to spruce beetle: 2010 plot re-assessment

Brad Hawkes, René Alfaro, Vince Waring, and Jenny Berg

Canada

The Pacific Forestry Centre, Victoria, British Columbia

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Abstract

In 2000 and 2002, 27 Forest Assessment plots were established within the area infested by spruce bark beetle, *Dendroctonus rufipennis* Kirby (Coleoptera: Scolytidae) in southwest Yukon. The study objective was to document long-term changes in white spruce (*Picea glauca* (Moench) Voss) mortality, stand structure, regeneration, surface vegetation, and surface woody fuel load (Garbutt et al. 2006). A partial re-measurement was conducted in 2010, which included 22 of the original 27 FA plots. Eight of the 22 FA plots were sampled to determine growth release of spruce overstorey and understorey, and establishment of regeneration. A number of plot maintenance activities were completed to ensure future re-measurements. Forest assessment plots were prioritised and buffered for long-term protection from forest management activities. Field sampling methodology followed the protocol used in Garbutt et al. (2006) except for spruce advanced regeneration and seedlings.

Overstorey spruce and deciduous species diameter-at-breast height increased from 18.2 cm to 18.9 cm. Overstorey spruce stand density (live and dead) increased from 1059 to 1124 stems per ha and volume from 184.4 to 198.7 m^3/ha. The volume of healthy overstorey spruce declined from 65.9 to 49.4 m^3/ha. Growth responses in live residual overstorey spruce were detected in four of eight plots. Fifty-nine percent of the spruce seedlings sampled were established between 2000 and 2008. Establishment dates of understorey and advanced regeneration suggested continuous spruce regeneration with a few decadal pulses detected in the 1820s and 1980s. Spot fire potential increased due to loose bark on the dead spruce. Coarse woody debris load remained similar to that reported in Garbutt et al. (2006) because few dead spruce had fallen over. A complete plot re-measurement should be considered starting in 2015 and include all attributes measured in Garbutt et al. (2006) and the 2010 re-measurement.

Keywords: spruce beetle, forest health, forest assessment, risk of fire, coarse woody debris, seedling establishment, growth and mortality of trees, stand structure.

Resume

En 2000 et 2002, 27 parcelles d'évaluation forestière ont été établies dans une région infestée par le dendroctone de l'épinette, Dendroctonus rufipennis Kirby (Coleoptera : Scolytidae), dans le sud-ouest du Yukon. Ces parcelles devaient permettre un suivi à long terme des changements survenant dans les peuplements d'épinette blanche (Picea glauca (Moench) Voss) en termes de mortalité, de structure du peuplement, de régénération, de végétation de surface et de charge en débris ligneux combustibles de surface (Garbutt et al., 2006). En 2010, nous avons effectué une nouvelle évaluation partielle de 22 des 27 parcelles initiales. Nous avons prélevé des échantillons dans huit de ces parcelles, en vue de déterminer la reprise de croissance des épinettes du couvert et du sous-étage ainsi que le taux d'établissement de la régénération. Nous avons aussi instauré diverses mesures d'entretien visant à permettre des réévaluations futures. Les parcelles d'évaluation forestière ont été priorisées et protégées par une zone tampon contre toute activité d'aménagement, en vue de leur conservation à long terme. Les échantillons ont été prélevés conformément au protocole utilisé par Garbutt et al. (2006), sauf en ce qui a trait à la régénération avancée et aux semis d'épinette.

Le diamètre à hauteur de poitrine moyen des épinettes et des feuillus du couvert est passé de 18,2 à 18,9 cm. La densité de peuplement des épinettes (mortes et vivantes) du couvert est passée de 1059 à 1124 tiges par ha et leur volume est passé de 184,4 à 198,7 m^3/ha. Cependant, le volume d'épinettes saines du couvert est passé de 65,9 à 49,4 m^3/ha. Dans quatre des huit parcelles, nous avons pu détecter un effet sur la croissance des épinettes vivantes résiduelles du couvert. Notre échantillon de semis d'épinettes comprenait 59 % de semis établis entre 2000 et 2008. Les dates d'établissement des épinettes du sous-étage et de la régénération avancée semblaient indiquer que la régénération de cette espèce était continue, avec quelques pulsations décennales durant les années 1820 et 1980. Le risque de foyers d'incendie isolés a augmenté à cause de la présence d'écorce lâche sur les épinettes mortes. La quantité de débris ligneux grossiers est demeurée semblable à celle mesurée par Garbutt et al. (2006), car peu d'épinettes mortes étaient tombées au sol. Il faudrait envisager une réévaluation complète des parcelles à compter de 2015; cette réévaluation devrait inclure tous les attributs mesurés dans le cadre des travaux de Garbutt et al. (2006) et de la réévaluation de 2010.

Mots clés : dendroctone de l'épinette, santé des forêts, évaluation forestière, risque d'incendie, débris ligneux grossiers, établissement des semis, croissance et mortalité des arbres, structure du peuplement.

1. Introduction

The spruce bark beetle, *Dendroctonus rufipennis* Kirby (Coleoptera: Scolytidae) is endemic to southwest Yukon Territory where it interacts with the only native conifer species, white spruce (*Picea glauca* [Moench] Voss). In 1994, the first signs of the outbreak of an epidemic were observed in Kluane National Park and Reserve. To date, the duration of this epidemic has surpassed previously recorded outbreaks in neighbouring British Columbia (Berg et al. 2006). As of 2008, the accumulated area of infestation was greater than 366 526 ha (Figure 1). The spruce beetle has engulfed the landscapes of the Alsek River drainage within Kluane National Park as well as public forest lands and First Nations settlement lands in the Shakwak Trench.

Insect disturbances play an important role in forest disturbance ecology. Given the influence of climate change in southwest Yukon, historical outbreak triggers such as windthrow, fire, or harvesting seem to be less important than: 1) long-term drought affecting host ability to mount defensive responses to bark beetle attack (Garbutt et al. 2006; Berg et al. 2006), 2) warm growing-season temperatures affecting spruce beetle population dynamics (Chavardès et al. 2012b), and 3) mild winters increasing winter survivorship and accelerating spruce beetle maturation from a 2-year cycle to a 1-year cycle (Werner 2006; Hard 1985).

The spruce beetle outbreak was a key driver in the development of a Strategic Forest Management Plan for the Champagne and Aishihik (CAFN) Territory. The plan indicates that the outbreak is having impacts on ecosystem functioning, including species composition, biodiversity, succession, and wildlife habitat (ARRC 2004). The extensive spruce mortality in the CAFN territory is expected to affect the CAFN traditional economy, potential commercial forest operations, and community fire risk. A monitoring program (scientific, traditional, and local observations) is a key tool in adaptive forest management (ARRC 2004). The long-term forest assessment (FA) plots in this study and plots established in 2012 by Parks Canada in Kluane National Park (Carmen Wong, Parks Canada, pers. comm., 2013) form a key part of an overall monitoring program for southwest Yukon to determine the impacts of the spruce beetle outbreak. The attributes sampled and methodology used in the Forest Assessment (FA) plots were one of the sources in the development of *Yukon Forestry*

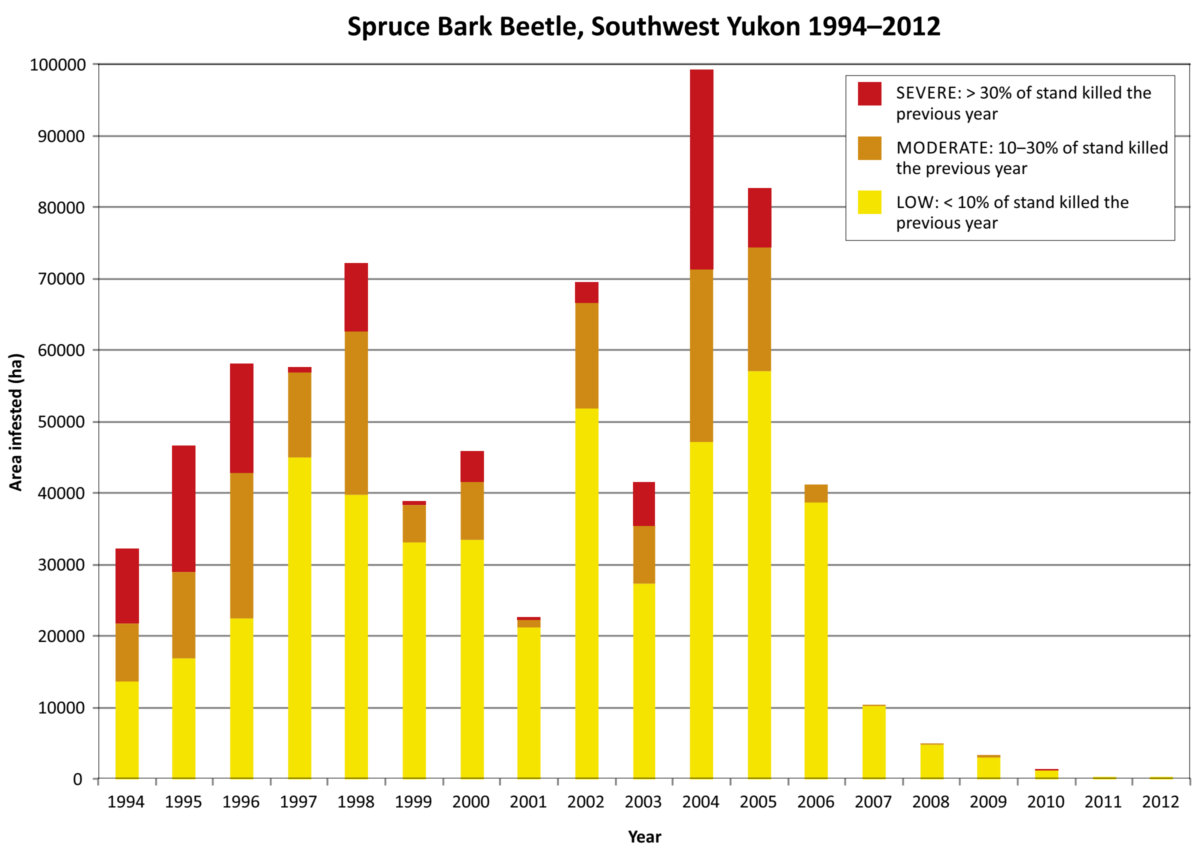


Figure 1. Area (ha) of spruce beetle mortality (by severity classes) in southwest Yukon from 1994 to 2011 (from GoY 2012).

Monitoring Program: Field Manual and Monitoring Protocols (Ogden 2008). The knowledge gained from the FA plots on spruce beetle impacts will inform programs directed at fire prevention and hazard abatement, sustainable forest management, reforestation, and public education.

In 2000 and 2002, 27 FA plots were established within the infestation area to document long-term changes in spruce mortality, stand dynamics, tree regeneration, surface vegetation, and surface woody fuel load in response to the spruce beetle outbreak in southwest Yukon (Garbutt et al. 2006).

The area of spruce beetle mortality has dropped significantly since 2006 providing the opportunity to document the final spruce mortality levels in the plots (Figure 1). In early 2010, discussions were initiated between the Yukon Forest Management Branch and Natural Resources Canada, Canadian Forest Service, Pacific Forestry Centre to determine if re-measurement of the spruce beetle FA plots was warranted. Garbutt et al. (2006) recommended that the first complete re-measurement should occur when the shedding of dead spruce branchlets and tree fall-down had increased

Figure 2. a) Spruce mortality in plot 23, b) the top of a dead spruce crown broken off, c) dead spruce fine- and medium-sized branchlets dropping off at crown base near plot 23, and d) windthrow of dead spruce in plot 23 where spruce beetle induced mortality started in 1994 (photographs a and d were taken in 2010; b and c were taken in 2006).

surface solar radiation to a level at which growth release could be detected in the advanced spruce regeneration and spruce seedlings had become established, and when no additional mortality from spruce beetle was occurring with the plots. They suggested that the growth release and seedling establishment criteria could be met as early as 2010 based on visual observations in plot 23, where mortality from spruce beetle first started in 1994 (Figure 2). The second criterion was determined to have been met in 2010 as spruce beetle mortality had dropped significantly since 2006 (Figure 1).

The study objective was to re-measure some of the original plots to document stand structure (e.g., overstorey spruce density and volume by health status); spruce mortality; dead spruce bark condition; surface woody fuel load; growth releases in live overstorey white spruce; and establishment dates of white spruce understorey, advanced regeneration, and seedlings. Plot maintenance activities were undertaken to ensure the option of future re-measurements. A priority rating system for plot protection was developed because a number of potential future land management activities (e.g., firewood cutting, logging to supply the local sawmill, and agricultural leases) could compromise plot integrity for future re-measurements.

2. Methods

2.1 Study Area Location

The study area was fully described in Garbutt et al. (2006). The original 27 FA plots were established in the Shakwak Trench, and the Bates/Mush Lakes and Alesk River valleys within Kluane National Park (Figure 3). The FA plots are located within three ecoregions of the Boreal Cordillera Ecozone: Ruby Ranges, Yukon-Stikine Highlands, and Yukon Southern Lakes (Smith et al. 2004).

2.2 Plot Re-measurement and Maintenance

In 2000 and 2002, 27 FA plots were established within the area infested by spruce bark beetle in southwest Yukon (Garbutt et al. 2006). Each plot was comprised of four subplots. Layout, attributes recorded, and how they were used in data analysis is described in Garbutt et al (2006). More recently, Carmen Wong (Parks Canada) established spruce beetle monitoring plots in Kluane National Park using a similar sampling protocol to that of this study, thereby augmenting the data collected from the FA plots being monitored in the park in this study. Plot data from Parks Canada was not used for this report.

Twenty-two of these FA plots (including subplots) were re-measured from May 31 to June 10, 2010 (Figure 3). Eight of the 22 re-measured FA plots were sampled to determine growth release of white spruce overstorey and understorey, and establishment of white spruce regeneration using tree cores and bole cross-sections. Table 1 summarizes which plots were re-measured and the attributes sampled in 2010. Only two of six plots located within Kluane National Park were re-measured due to lack of road access.

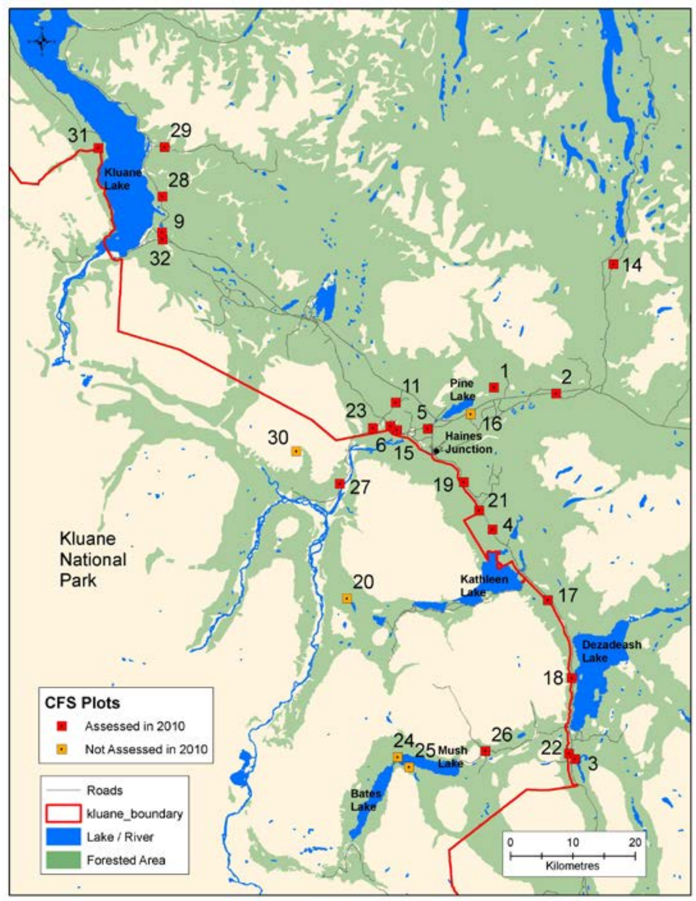


Figure 3. Location of Yukon spruce beetle forest health plots re-assessed in 2010.

Table 1. Yukon spruce beetle forest assessment plots (established by the Canadian Forest Service, Pacific Forestry Centre) that were re-assessed in 2010.

	Re-measurements		New Sampling in 2010				
Est. in 2000 and 2002 (Plot No.)	Overstorey Trees: Fixed-area Plots	Coarse Woody Debris	Spruce Seedling Density (New)	Spruce Overstorey Increment Cores (New)	Spruce Understorey Cross Sections (New)	Spruce Advanced Regeneration Cross Sections (New)	Spruce Seedling Destructive Samples (New)
1	✓	✓	✓	✗	✗	✗	✗
2	✓	✓	✓	✓	✓	✓	✗
3	✓	✓	✓	✗	✗	✗	✗
4	✓	✓	✓	✓	✓	✓	✓
5	✓	✓	✓	✓	✓	✓	✓
6	✓	✓	✓	✓	✓	✓	✓
9	✓	✓	✓	✗	✗	✗	✗
11	✓	✓	✓	✓	✓	✓	✓
14	✓	✓	✓	✓	✓	✓	✓
15	✓	✓	✓	✗	✗	✗	✗
16[1]	✗	✗	✗	✗	✗	✗	✗
17	✓	✓	✓	✗	✗	✗	✗
18	✓	✓	✓	✗	✗	✗	✗
19	✓	✓	✓	✓	✓	✓	✓
20[2]	✗	✗	✗	✗	✗	✗	✗
21	✓	✓	✓	✗	✗	✗	✗
22	✓	✓	✓	✗	✗	✗	✗
23	✓	✓	✓	✗	✗	✗	✗
24[2]	✗	✗	✗	✗	✗	✗	✗
25[2]	✗	✗	✗	✗	✗	✗	✗
26	✓	✓	✓	✗	✗	✗	✗
27	✓	✓	✓	✗	✗	✗	✗
28	✓	✓	✓	✓	✓	✓	✓
29	✓	✓	✓	✗	✗	✗	✗
30[2]	✗	✗	✗	✗	✗	✗	✗
31	✓	✓	✓	✗	✗	✗	✗
32[3]	✗	✗	✗	✗	✗	✗	✗

[1] Trees removed due to agricultural lease.
[2] Plots located in remote locations in Kluane National Park that required boat or helicopter access.
[3] Subplot 1 was removed due to firewood cutting; the plot was compromised.

Field sampling methodology followed the protocol outlined in Garbutt et al. (2006) for all attributes recorded in 2000 and 2002, and those re-measured in 2010. Spruce beetle-attack categories used in 2000/2002 and 2010 sampling are those described in Shore (1985) and defined in Appendix 1. Re-measurement of the spruce understorey (trees <1.3 m height, and trees >1.3 m height, but <10 cm DBH as defined in Garbutt et al. 2006) density was not completed as time limitations did not allow for re-measurement using the nearest neighbour sampling protocol. To distinguish spruce understorey that might have regenerated as a result of the spruce beetle outbreak, the understorey height class (<1.3 m) was split into two classes: advanced regeneration (>10 cm <1.3 m) and seedlings (<10 cm). Seedling density was sampled in 2010 using two circular (3.99 m radius) fixed-area plots located at 15 and 25 m on each subplot transect. A total of 88 seedlings were destructively sampled in seven plots.

As part of the 2010 FA plot re-measurement, a number of plot maintenance activities were completed to ensure future re-measurements (Figure 4):

- Took global positioning system (GPS) readings of each point of commencement (POC) and the starting point of each of four subplots. Repainted POC stake and nearby trees to assist in relocation.
- Photographed each subplot transect at the 10 m point using a standard-sized sign located on top of a graduated pole for scale.
- Repainted all standing overstorey tree numbers and nailed new numbered aluminum tags on each plot tree.
- Replaced any missing metal pins that marked the start and end of each subplot transect.
- Repainted all locations where the line-intersect transect crossed coarse woody debris.

Figure 4. Photographs illustrating a) re-painting of coarse woody debris sample transect intersection, b) plot tree numbers, c) point of commencement stakes, and d) placement of new plot tree aluminum numbered tags.

2.3 Plot Location, Priority Rating, and Buffering

The Yukon Forest Management Branch requested that the Canadian Forest Service develop a priority rating for protection of the FA plots located outside Kluane National Park for future re-measurements. This request resulted from the potential for plot disturbance by a number of possible future land management activities (e.g., firewood cutting, logging to supply the local sawmill, and agricultural leases) that could compromise plot integrity for future re-measurements. As part of this activity we also determined if a plot buffer was needed to protect the plot from these disturbances. A buffer area and shape was designed that would ensure the plots would not be influenced by any planned disturbance adjacent to a plot.

GPS co-ordinates of 22 plots (including subplots and point of commencement [POC]) revisited in 2010 were updated using a Garmin GPSMAP 76CSx unit (Datum NAD83). ArcGIS software was used to generate one updated GPS co-ordinate (i.e., centroid) per plot and determine the cardinal extents of plots identified as requiring a buffer. The FA priority rating (low, moderate, and high) was based on the plot's location, site characteristics, and the presence of human disturbance near the plots.

The original plot location spreadsheet from Garbutt et al. 2006 was imported into ArcGIS and, using the northing and easting columns, two point shapefiles were created (for zones 7 and 8). These point shapefiles were then re-projected onto the Albers projection used by the Government of Yukon (Figure 3), with the following parameters:

Projection: Albers	2nd Standard Parallel: 68.0
Units: Meters	Latitude of Origin: 59.0
Central Meridian: -132.5	False Easting: 500000.0
1st Standard Parallel: 61.667	False Northing: 500000.0

The two shapefiles were merged into one file using the "Merge" command and the POC locations were deleted from the dataset. The "Buffer" command was used to create 50-m-circular buffers around each point (i.e., subplot). The "Dissolve" command was used to aggregate overlapping features (i.e., all subplots for each plot were merged together). The "Feature to Point" command was used to create a centroid for each dissolved polygon (Figure 5). These centroids were used as the plot locators for the FA plots re-assessed in 2010. For those plots not revisited in 2010, the same co-ordinates determined during plot establishment in 2000 and 2002 were used for mapping plot location.

The "Feature Envelope to Polygon" command was used to generate the cardinal (northern, eastern, southern, and western) extents of the dissolved 50-m plot buffer polygons.

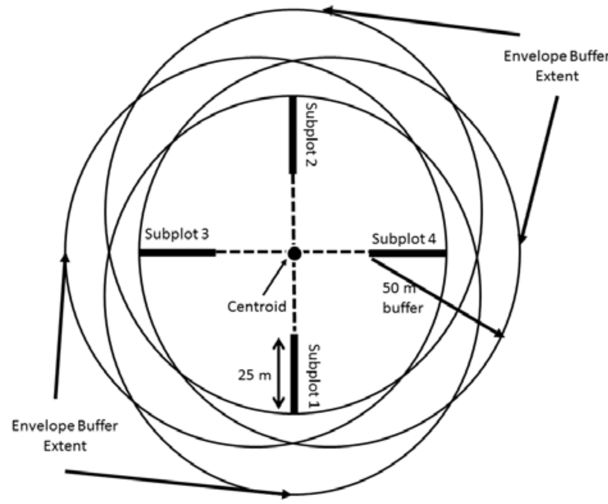


Figure 5. Diagram of centroid and envelope extents determined by 50-m-circular buffers of subplots.

The "Feature Vertices to Point" command was used on the polygon envelope file to create a point file of the four corners of the envelope. The "Add XY Coordinates" command generated the northing and easting of each point with these values being used to determine the maximum cardinal extents of the 50-m buffer polygons. The "Layer To KML" command created a .kmz file of the buffered polygons that allowed their importation into Google Earth in order to visually determine their general location.

2.4 Data Analysis: Change in Stand Attributes from 2000/2002 to 2010

Data analysis summaries published as tables in Garbutt et al. (2006) were updated for this report with 2010 re-measured plot data to examine changes in white spruce and deciduous stand structure, volume, density and mortality, woody debris fuel load, relative fire hazard rating, and spot fire potential. Tables 1, 3, 6, 7, and 8 show data for 2000/2002 and 2010. There are a few 2000/2002 table values in the updated 2010 tables that are different when compared to those published in Garbutt et al. (2006) due to error checking of 2000/2002 databases and analyses. Incidence of root disease and nearest neighbour sampling was not redone in 2010.

2.5 Fire Hazard Rating and Spot Fire Potential

Three protocols to measure the fire hazard rating were used when the study was established, but only one (the dead tree rating) was used for the 2010 FA plot re-measurements. Garbutt et al. (2006) estimated spot fire potential by observing the presence or absence of loose bark on each white spruce in a plot and then determining the percentage of white spruce in the stand with loose bark. In 2010, a more detailed loose bark assessment was done using seven bark retention codes (Appendix 1). To compare loose bark estimates from 2000/2002 with those in 2010, white spruce with bark retention code 1 were classified as having no loose bark and codes 2–6 as having loose bark. The number of white spruce in a plot in each of these two retention code groupings was divided by the total number of white spruce in the plot to obtain an estimate the percentage of white spruce with loose bark. An attribute not measured by Garbutt et al. (2006), but estimated in 2010 for the overstorey spruce trees, was crown condition class (Appendix 1). This attribute is not reported in this report because data analysis was not completed. Crown condition class should be considered for re-measurement when a complete re-measurement is done and be included in the next report. Prior to dead white spruce falling over, their crowns quickly lose their needles but more slowly shed their twigs and branches, which can increase light levels and surface woody fuel load. This attribute will be useful in future re-measurements to document canopy bulk density reduction, an indicator of crown fire spread potential.

2.6 Dendrochronological Study

The 2010 re-measurement included new sampling (Table 1) as part of a growth release dendrochronological study of overstorey and understorey spruce by Rene Alfaro (Canadian Forest Service, Pacific Forestry Centre). Increment cores and basal cross-sections were prepared in the lab following standard dendrochronological procedures as outlined by Stokes and Smiley (1968).

Overstorey tree cores were scanned and measured using WinDENDRO™ (Regent Instruments Inc.1995) with a measurement precision of 0.01 mm. COFECHA (Holmes 1983) software was used to cross-date tree ring chronologies and assign a calendar year to each tree ring. Mean serial correlations for each plot in COFECHA were well above a 99% confidence threshold ($p \geq 0.3281$) indicating the cross-dating methods produce an acceptable level of accuracy in identifying tree ring dates. After accounting for accuracy in tree ring dates, each tree sample was de-trended for tree-ring growth widths by applying a negative exponential curve ($K > 0$) linear regression or a horizontal line where appropriate (Cook and Krusic 2005) using ARSTAN (version 4.1). ARSTAN was used to assemble the standardized ring widths as a master chronology, representing the average tree-ring width for each year for all tree-ring series used.

To examine overstorey spruce growth release, master chronologies were grouped by similar overall patterns using factor analysis conducted with Statistica™ (StatSoft Inc., Version 9, 2010) software on the eight standardized chronologies. Factor analysis required a common reference; therefore, all chronologies were truncated to include the time

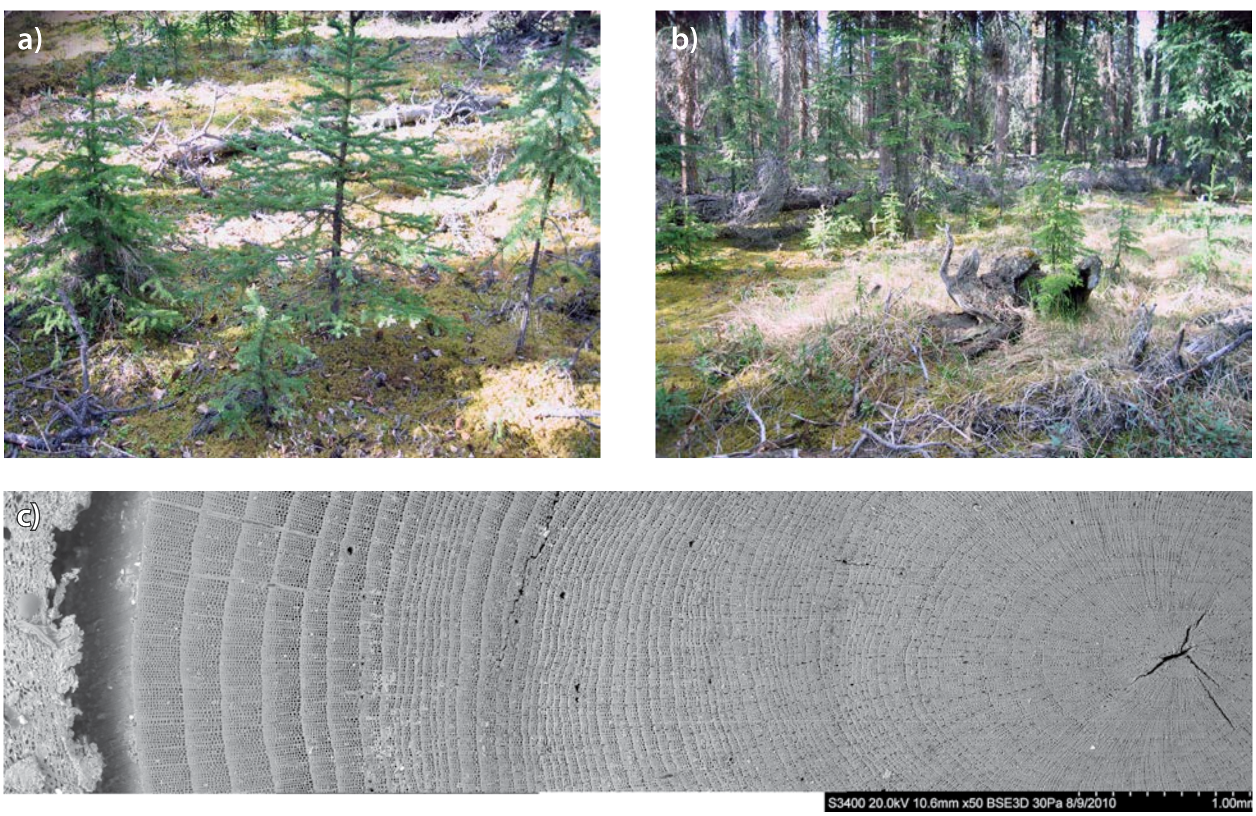


Figure 6. a) and b) Examples of white spruce advanced regeneration (>10 cm < 1.3 m height class) that basal cross-sections were collected for to determine year of establishment and c) scanned electron microscope image of a spruce advanced regeneration cross-section.

period 1903–2009. Two factors were extracted in the analysis. The eight plots were partitioned into plot groupings based on significant loading values and those were then prioritised based on the highest factor loading value.

Estimates of establishment dates for overstorey trees used an age correction of 53 years since the increment cores were taken at 1.3 m (diameter at breast height [DBH]). The age correction was based on the average age of white spruce advanced regeneration that was 1.3 m in height. The establishment dates for understorey, advanced regeneration, and seedlings were determined by counting annual tree rings to the innermost ring of the basal cross-section. Understorey cross-sections were scanned and counted with WinDENDRO™. However, due to difficulties in measuring narrow rings in suppressed white spruce advanced regeneration and seedlings [Figures 6 c); and 7 b), c), and d)], a scanning electron microscope (SEM) was used to create high resolution images. Seedling ring counts were done visually using the SEM images while the advanced regeneration SEM images were imported into WinDENDRO™ to determine ring widths and counts. Destructively sampled white spruce seedlings were photographed using a ruler for scale [Figure 7 b), c), and d)].

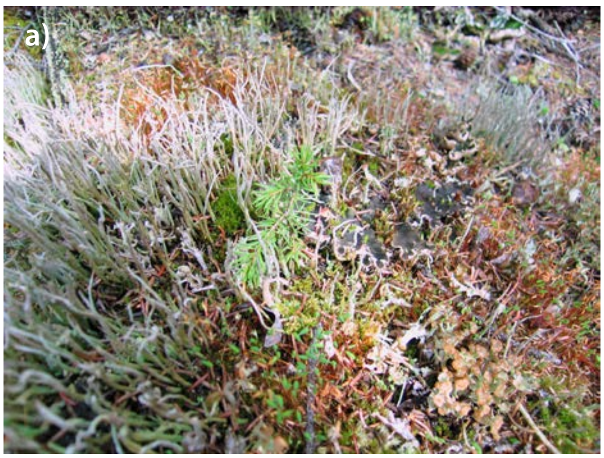
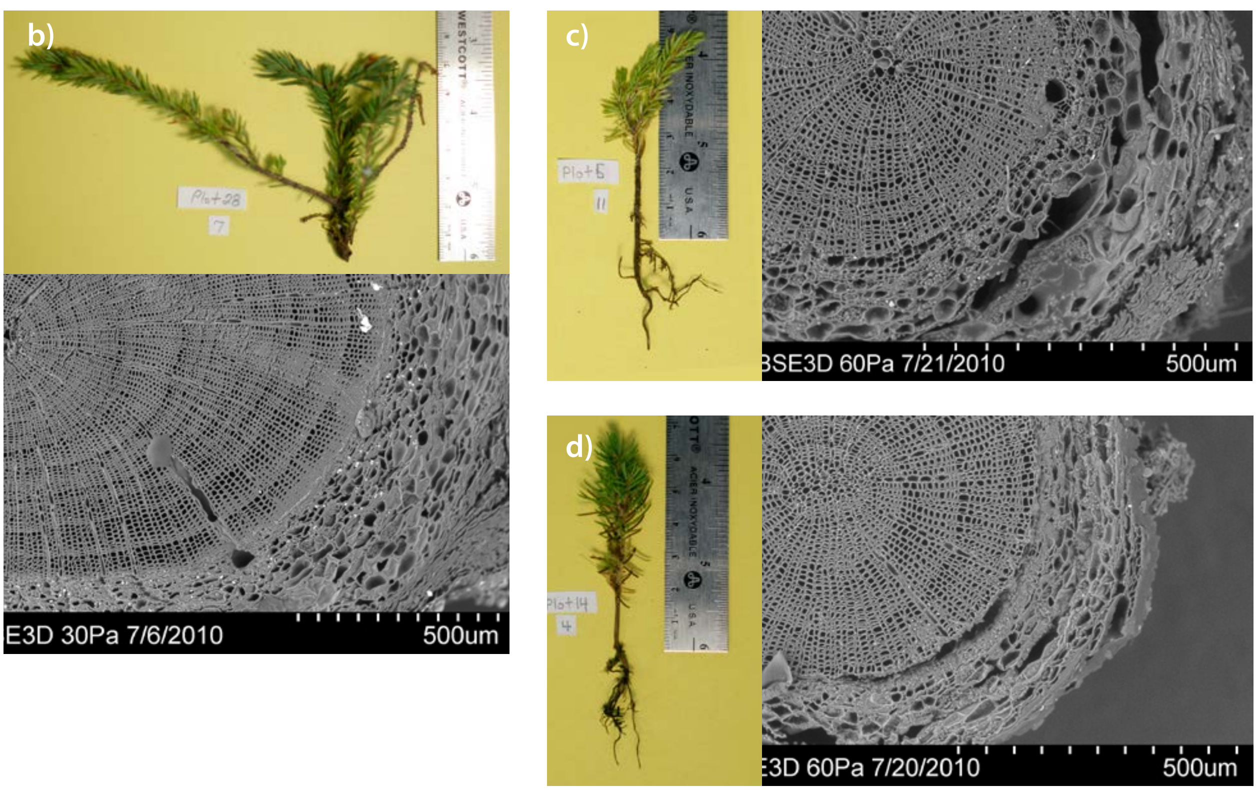


Figure 7. a) Photograph of a seedling (<10 cm height class) on a sample plot and three examples of seedling basal cross-sections scanned with an electron microscope: seedling height and establishment year were b) 7.5 cm, 1992, c) 5.0 cm, 1997, and d) 6.0 cm, 2005.



3. Results

3.1 Plot Location, Priority Rating, and Buffering

All FA plots located in Kluane National Park were assigned a high priority for retention as there was minimum risk of human activity or development impacting them. Plots in immature stands of white spruce with edge effects were assigned a moderate rating while those that already had been partially impacted by harvesting were assigned a low rating.

If human disturbances are planned near any FA plot that has subplots laid out in a straight line, then each subplot within a sampled stand should be buffered individually especially if the priority rating is moderate or high (Figure 8). No buffering is required for plots located within Kluane National Park since there is a low probability that human disturbance will impact plot integrity. Seventeen plots were identified for potential buffering (Table 2 and Figure 9).

Table 2. Forest assessment plot co-ordinates, assigned priority rating, and buffer envelope with north, east, south, and west cardinal extents.

							Envelope Buffer			
Plot	Easting	Northing	Zone	Assessed 2010	Priority	YK Buffer	North	East	South	West
P1	372515.1	6748573.1	8	Yes	Low	N	*	*	*	*
P2	382491.8	6747993.2	8	Yes	High	Y	6748088.3	382610.9	6747900.7	382374.1
P3	387873.9	6689558.6	8	Yes	Moderate	Y	6689651.1	387993.0	6689464.9	387756.0
P4	373259.9	6725801.7	8	Yes	High	Y	6725878.0	373386.8	6725723.0	373134.2
P5	362200.5	6741524.2	8	Yes	High	Y	6741629.9	362287.2	6741416.4	362109.1
P6	356238.7	6741678.5	8	Yes	High	Y	6741762.6	356383.9	6741591.4	356092.1
P9	642542.9	6769397.3	7	Yes	Moderate	Y	6769538.2	642672.9	6769253.8	642417.1
P11	356930.3	6745486	8	Yes	High	Y	6745594.0	357036.3	6745379.0	356822.7
P14	390841.3	6769060.4	8	Yes	Moderate	Y	6769178.0	390923.2	6768941.0	390762.8
P15	357328	6741072.3	8	Yes	High	Y	6741197.0	357394.9	6740947.0	357265.1
P16	368995	6744148	8	No	n/a	N	*	*	*	*
P17	382545.4	6714865.1	8	Yes	High	Y	6714964.0	382661.5	6714766.0	382429.5
P18	386875	6702537.2	8	Yes	High	Y	6702603.0	386996.0	6702467.0	386756.0
P19	368325.4	6733207.2	8	Yes	High	Y	6733272.0	368455.5	6733147.8	368194.5
P20	350440	6713828	8	No	High	N	*	*	*	*
P21	370991.4	6728763.1	8	Yes	High	Y	6728827.7	371068.9	6728692.3	370917.4
P22	386874.7	6690437.3	8	Yes	High	Y	6690500.7	386952.5	6690372.4	386799.6
P23	353467.2	6741266.4	8	Yes	High	Y	6741332.4	353545.4	6741201.3	353390.6
P24	359547	6688742	8	No	High	N	*	*	*	*
P25	361460	6687212	8	No	High	N	*	*	*	*
P26	373560.1	6690254.3	8	Yes	High	N	*	*	*	*
P27	348521.1	6732104.2	8	Yes	High	N	*	*	*	*
P28	641869.8	6775104.7	7	Yes	High	Y	6775173.7	641947.1	6775030.9	641787.8
P29	641150.6	6783055.5	7	Yes	Low	N	*	*	*	*
P30	341353	6737053	8	No	High	N	*	*	*	*
P31	630677.8	6781446.4	7	Yes	High	Y	6781521.3	630751.6	6781368.7	630603.9
P32	642834.7	6768311	7	Yes	Low	N	*	*	*	*

* no data

The location and priority rating of the Canadian Forest service FA plots in southwest Yukon are presented in Figure 8. The FA plots that require a 50-m buffer are presented in Figure 9.

3.2 Overstorey White Spruce and Deciduous Species Tree Counts and DBH

The total number of white spruce and deciduous species counted in each plot (sum of the four subplots), and average DBH and its range are presented in Table 3. Based on the re-measured plots, average DBH in 2000/2002 was 18.2 cm and increased to 18.9 cm in 2010. The range in DBH did not change. The total number of trees (white spruce and deciduous species) counted in each plot increased between 2000/2002 and 2010, from 890 to 951. The increase in tree counts was mainly due to growth of co-dominant and intermediate canopy spruce ≥10.0 cm DBH (cut-off for inclusion of trees in fixed-area subplot) in the last 8–10 years. The increase in tree counts also indicates that few dead spruce, which are no longer included in the plot tallies, have fallen over.

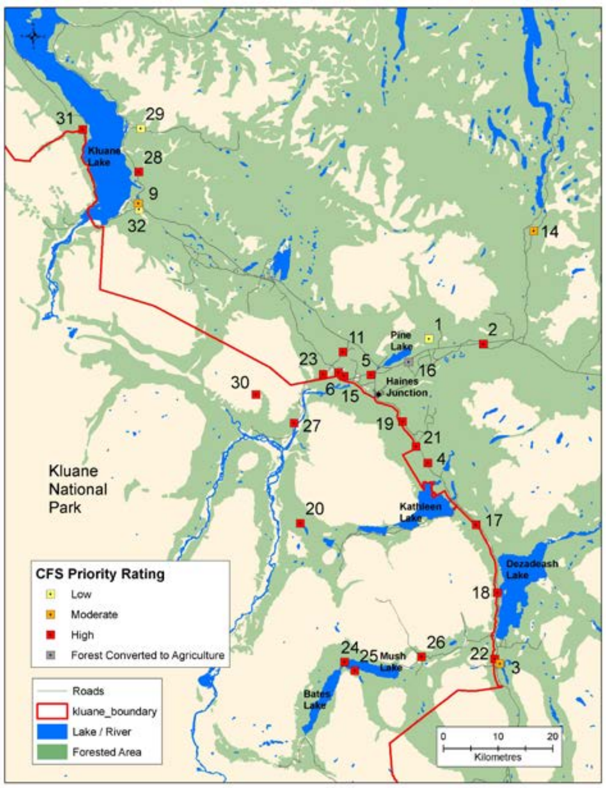


Figure 8. Location and priority rating of the Canadian Forest Service spruce beetle forest assessment plots in southwest Yukon.

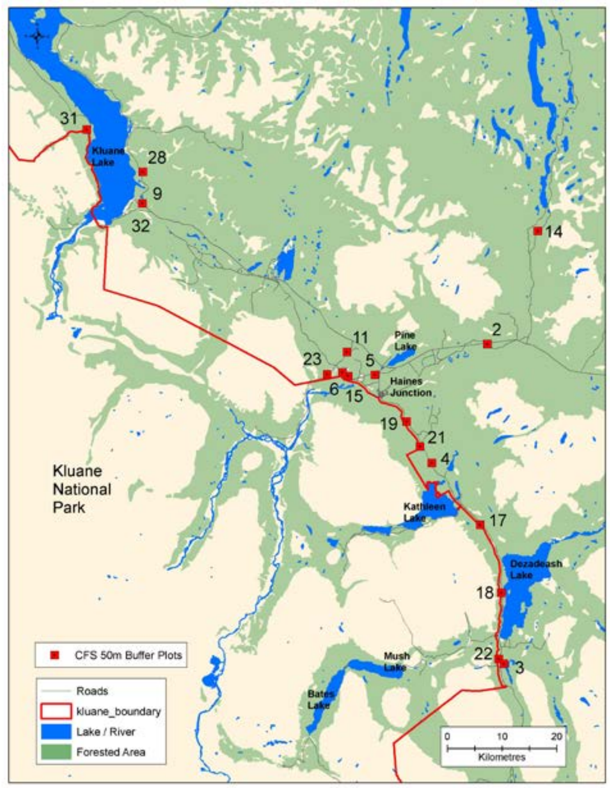


Figure 9. Location of Canadian Forest Service spruce beetle forest assessment plots that require 50-m buffers.

Table 3. Tree (>10 cm DBH) counts for white spruce and deciduous species, and average DBH (all species) and its range for plots established in 2000/2002 and re-measured in 2010.

	Established in 2000 and 2002[1]				Re-measured in 2010			
Plot No.	No. Spruce	No. Deciduous[2]	Avg. DBH[3] (cm)	DBH Range	No. Spruce	No. Deciduous	Avg. DBH (cm)	DBH Range
1	62	1	17.9	10–46	62	1	19.0	11–41
2	35	5	16.3	10–36	43	4	16.2	10–35
3	62	12	17.4	10–38	62	12	18.0	10–37
4	37	11	15.5	10–30	44	14	16.5	10–28
5	72	0	12.3	10–33	72	0	17.7	10–33
6	37	0	22.1	10–34	36	0	23.4	10–37
9	37	0	15.5	10–35	42	0	16.1	10–29
11	67	6	13.4	10–27	73	7	15.0	10–37
14	57	0	15.9	10–31	64	0	16.4	10–31
15	43	0	20.7	10–57	47	0	21.5	10–57
16	48	2	17.4	10–37	n/a	n/a	n/a	n/a
17	24	13	19.1	10–36	28	12	20.1	10–35
18	24	13	20.8	10–43	23	12	20.1	10–31
19	58	3	14.2	10–28	63	2	14.9	8.7[4]–31
20	62	0	18.5	10–44	n/a	n/a	n/a	n/a
21	51	23	18.2	10–35	51	20	18.9	9.64–35
22	34	0	18.7	10–34	33	0	20.7	11–34
23	28	0	26.2	12–47	28	0	25.7	12–41
24	62	3	14.5	10–44	n/a	n/a	n/a	n/a
25	45	0	16.0	10–35	n/a	n/a	n/a	n/a
26	19	9	16.7	10–29	20	10	17.5	10–31
27	30	0	24.4	10–37	29	0	24.5	12–37
28	53	0	20.2	10–34	61	0	18.5	10–34
29	27	0	12.6	10–23	41	1	12.3	10–23
30	31	0	17.8	10–38	n/a	n/a	n/a	n/a
31	34	0	24.4	10–43	32	0	24.7	10–43
32	88	0	18.2	10–31	n/a	n/a	n/a	n/a

[1] Plots 1–19 were established in 2000; Plots 20–32 were established in 2002.
[2] Trembling aspen (*Populus tremuloides*), except in plot 18, which also had balsam poplar (*Populus balsamifera*) and willow (*Salix glauca*).
[3] DBH= diameter at breast height (1.3 m).
[4] DBH range should be >10 cm, however, three white spruce re-measured in 2010 were <10 cm DBH indicating a measurement error in 2000. The 2010 DBH measurements were used in all data analysis.

Table 4. White spruce dead tree rating and spot fire potential components of the fire hazard rating system for plots established in 2000/2002 and 2010.

	Established in 2000 and 2002[1]				Re-measured in 2010			
Plot No.	Dead Spruce per ha	Dead Tree Rating[2]	Loose Bark (%)	Spot Fire Potential[3]	Dead Spruce per ha	Dead Tree Rating	Loose Bark (%)	Spot Fire Potential
1	325	1	14	1	950	3	61	3
2	25	1	0	1	225	1	21	2
3	825	2	42	3	1225	3	81	3
4	150	1	8	1	400	1	32	3
5	725	2	39	3	1025	3	58	3
6	340	1	17	2	480	2	56	3
9	60	1	0	1	200	1	20	2
11	275	1	1	1	500	2	25	2
14	425	1	28	2	450	1	59	3
15	275	1	21	2	350	1	32	3
16	300	1	18	2	n/a	n/a	n/a	n/a
17	250	1	22	2	350	1	50	3
18	125	1	3	1	350	1	70	3
19	525	2	27	2	800	2	48	3
20	1000	3	33	3	n/a	n/a	n/a	n/a
21	525	2	12	1	825	2	67	3
22	475	1	47	3	625	2	82	3
23	350	1	43	3	425	1	64	3
24	325	1	6	1	n/a	n/a	n/a	n/a
25	425	1	22	2	n/a	n/a	n/a	n/a
26	50	1	0	1	175	1	50	3
27	425	1	30	2	450	1	72	3
28	1000	3	63	3	1025	3	74	3
29	50	1	4	1	575	2	63	3
30	500	2	52	3	n/a	n/a	n/a	n/a
31	225	1	26	2	325	1	78	3
32	1725	3	74	3	n/a	n/a	n/a	n/a

[1] Plots 1–19 were established in 2000; Plots 20–32 were established in 2002.
[2] Dead tree rating is based on the number of dead spruce trees per hectare: 1: < 500; 2: > 500 < 900; 3: > 900.
[3] Spot fire potential is based on percentage of white spruce in the stand with loose bark: 1: > 0 < 15; 2: > 15 < 30; 3: > 30.

3.3 Fire Hazard Rating and Spot Fire Potential

The "dead tree" component of the fire hazard rating did not significantly change in 8–10 years, remaining at 2 (Table 4). The spot fire potential increased between 2000/2002 and 2010 from 2 to 3, the highest rating, because of an increase in loose bark on dead spruce (Figure 10).

3.4 Coarse Woody Debris

Coarse woody debris (diameter > 7 cm at transect interception point) was re-measured in 2010 using the existing line-intersect transect in each of the subplots. For the plots re-measured in 2010, coarse woody debris load averaged 16.99 tonnes/ha (range 0 to 56.82 tonnes/ha) in 2000 and 2002 (Table 5). Coarse woody debris load in 2010 averaged 16.37 tonnes/ha (range 0.86 to 64.21 tonnes/ha). Eleven out of 21 re-measured plots in 2010 had a lower coarse woody debris load than in 2000 and 2002 (Table 5). This probably was the result of not being able to re-measure the diameter of each individual piece of coarse woody debris at the same location (due to the lack of paint or nails marking the spot measured in 2000 and 2002) along the line-intersect transect. Some of the 2000 and 2002 log diameters were measured with a cruise stick and not a large calliper, which is more accurate. It was also difficult to obtain the same bearing of the line-intersect transect as there were no pins at the end of transects for reference. In 2010, 72% of the coarse woody debris was classified as decay classes 1–3 (sound to partially decayed) and 28% was decay classes 4 and 5 (mostly decayed) (decay classes listed in Appendix 1). Figure 11 shows coarse woody debris load on plots 27, 5, and 23, illustrating a range from the lowest to highest coarse woody debris load.

Table 5. Coarse woody debris (>7.0 cm diameter) mass for plots established in 2000/2002 and re-measured in 2010.

Plot No.	2000 and 2002 (tonnes/ha)	2010 (tonnes/ha)
1	9.78	5.17
2	11.21	4.94
3	22.47	17.88
4	0.47	1.91
5	18.98	22.47
6	3.90	8.53
9	23.42	22.93
11	18.63	7.71
14	10.28	7.40
15	13.13	11.46
16	17.48	n/a
17	2.41	6.27
18	41.04	39.33
19	2.08	0.86
20	28.99	n/a
21	1.84	16.57
22	16.57	27.61
23	56.82	64.21
24	6.13	n/a
25	26.25	n/a
26	22.28	17.97
27	0	6.55
28	9.67	12.59
29	14.26	5.22
30	6.07	n/a
31	40.03	49.27
32	15.99	n/a

Figure 10. a) and b) Examples of loose bark on dead white spruce in plots 17 and 31. This loose bark could be potential spot fire material. c) Loose bark can also occur on coarse woody debris. (All photographs were taken in 2010.)

Figure 11. Coarse woody debris on plots a) 27, b) 5, and c) 23 illustrating a range from the lowest to highest coarse woody debris load.

3.5 Overstorey Stand Density, Volume, and Spruce Beetle Mortality

For the plots re-measured in 2010, white spruce stand density (live and dead) in 2000 and 2002 averaged 1059 stems per ha ranging from 475 to 1800. There was a small increase in average white spruce stand density in 2010 to 1124 stems per ha ranging from 500 to 1800 (Table 6). Half of the plots had an increase in stand density while the rest were evenly split between a decrease and no change. The increase in overstorey white spruce density was because spruce <10 cm DBH had grown enough in diameter since 2000/2002 to now be included in the overstorey fixed-area plots. The decrease in stand density was due to dead spruce falling over.

Approximately half of the plots originally sampled and re-measured in 2010 had deciduous species (trembling aspen and balsam poplar) present. Deciduous stand density (live and dead) in 2000 and 2002 averaged 245 stems per ha ranging from 25 to 600. There was a small decrease in average deciduous stand density in 2010 to 216 stems per ha ranging from 25–500 (Table 6). Forty percent of the plots had an increase in deciduous stand density, 40% had a decrease, and 20% had no change. Deciduous density increased because trees <10 cm DBH had grown enough in diameter since 2000/2002 to now be included in the overstorey fixed-area plots, while the decrease in density was due to mortality since deciduous species have a shorter biological lifespan than white spruce and are early successional species.

For the plots re-measured in 2010, white spruce volume (live and dead) in 2000 and 2002 averaged 184.4 m^3/ha ranging from 39.7 to 292.6 m^3/ha. There was a small increase in average white spruce stand volume in 2010 to 198.7 m^3/ha ranging from 61.7 to 277.3 m^3/ha (Table 7). Seventy-six percent of the plots had an increase in stand volume while the rest had a decrease. Overstorey white spruce volume increased because the remaining live white spruce and trees <10 cm DBH had grown enough in diameter since 2000 and 2002 to now be included in the overstorey fixed-area plots. The decrease in stand volume was due to dead spruce falling down.

Table 6. Density of overstorey white spruce and deciduous species for plots established in 2000/2002 and re-measured in 2010.

	Stand Density (stems/ha) 2000 and 2002			Stand Density (stems/ha) 2010		
Plot No.	**Spruce**	**Deciduous**	**Total**	**Spruce**	**Deciduous**	**Total**
1	1550	25	1575	1550	25	1575
2	875	125	1125	1075	100	1175
3	1550	300	1850	1550	300	1850
4	925	275	1200	1100	350	1450
5	1800	0	1800	1800	0	1800
6	740	0	740	720	0	720
9	740	0	925	840	0	1000
11	1675	150	1825	1825	175	1975
14	1475	0	1475	1600	0	1600
15	1075	0	1075	1175	0	1175
16	1200	50	1250	n/a	n/a	n/a
17	600	325	925	700	300	1000
18	600	325	925	575	300	875
19	1450	75	1525	1575	50	1625
20	1550	0	1575	n/a	n/a	n/a
21	1275	575	1875	1275	500	1775
22	850	0	850	825	0	825
23	700	0	700	700	0	700
24	1550	75	1625	n/a	n/a	n/a
25	1125	0	1125	n/a	n/a	n/a
26	475	225	700	500	250	750
27	750	0	750	725	0	725
28	1325	0	1325	1525	0	1525
29	675	0	675	1025	25	1050
30	775	0	775	n/a	n/a	n/a
31	850	0	850	800	0	800
32	2200	0	2200	n/a	n/a	n/a

Table 7. Volume of overstorey white spruce and deciduous species for plots established in 2000/2002 and re-measured in 2010.

	Volume (m^3/ha) 2000 and 2002			Volume (m^3/ha) 2010		
Plot No.	Spruce	Deciduous	Total	Spruce	Deciduous	Total
1	281.1	19.4	300.5	272.1	23.7	295.8
2	134.0	14.2	148.1	145.0	13.1	158.1
3	240.0	42.8	282.8	246.5	44.8	291.3
4	111.1	19.1	130.2	149.7	33.9	183.6
5	284.6	0.0	284.6	277.3	0.0	277.3
6	214.2	0.0	214.2	221.7	0.0	221.7
9	82.8	0.0	82.8	101.0	0.0	101.0
11	121.9	7.2	129.1	187.3	9.6	196.8
14	186.8	0.0	186.8	213.5	0.0	213.5
15	296.7	0.0	296.7	327.4	0.0	327.4
16	188.5	27.1	215.6	n/a	n/a	n/a
17	90.4	78.8	169.3	135.1	82.6	217.7
18	122.1	36.9	159.0	130.3	45.4	175.7
19	123.5	12.1	135.5	150.4	14.2	164.6
20	288.8	0.0	288.8	n/a	n/a	n/a
21	243.4	76.4	319.8	234.2	87.7	321.9
22	185.2	0.0	185.2	191.0	0.0	191.0
23	287.7	0.0	287.7	268.8	0.0	268.8
24	136.3	43.3	179.7	n/a	n/a	n/a
25	132.0	0.0	132.0	n/a	n/a	n/a
26	52.1	43.7	95.7	68.9	46.7	115.6
27	214.5	0.0	214.5	232.5	0.0	232.5
28	238.3	0.0	238.3	269.4	0.0	269.4
29	39.7	0.0	39.7	61.7	0.9	62.6
30	132.9	0.0	132.9	n/a	n/a	n/a
31	292.5	0.0	292.5	268.4	0.0	268.4
32	378.8	0.0	378.8	n/a	n/a	n/a

For the plots that contained deciduous species, stand volume (live and dead) in 2000 and 2002 averaged 35.4 m^3/ha ranging from 4.8 to 83.5 m^3/ha. There was a small increase in average deciduous stand volume in 2010 to 40.3 m^3/ha ranging from 1.3 to 86.1 m^3/ha due to trees <10 cm DBH that had grown enough in diameter since 2000 and 2002 to now be included in the overstorey fixed-area plots (Table 7). Half of the plots had an increase in volume and half had a decrease due to the dead spruce falling down.

Spruce beetle-induced mortality declined significantly since 2000/2002 as there was no current attack recorded in any of the re-measured FA plots (Table 8a). There was an increase in tree volume of partially beetle-attacked spruce, increasing from 11.5 m^3/ha in 2000/2002 to 24.6 m^3/ha in 2010, although most of the beetle activity would have been from 2000/2002 to 2006 (Table 8b). The volume of healthy overstorey white spruce (not attacked by spruce beetle) declined from 65.9 to 49.4 m^3/ha. The volume of grey spruce (attacked by spruce beetle and killed 2 or more years previously) increased from 73.8 to 121.7 m^3/ha from 2000/2002 to 2010 (Table 8b). There was a small amount of dead spruce volume attributed to causes other than spruce beetle in both 2000/2002 and 2010 (Table 8b).

Table 8a. Volume of overstorey white spruce by spruce beetle-attack categories: total, healthy, current, and red.

	Volume (m^3/ha) by Spruce Beetle-attack Category[1]							
	Total		Healthy		Current		Red	
Plot No.	2000/2002	2010	2000/2002	2010	2000/2002	2010	2000/2002	2010
1	300.5	295.8	160.0	86.1	47.8	0.0	0.0	0.0
2	148.1	158.1	145.0	74.7	0.0	0.0	0.0	0.0
3	282.8	291.3	154.3	72.3	0.0	0.0	0.0	0.0
4	130.2	183.6	84.3	75.9	11.9	0.0	0.0	0.0
5	284.6	277.3	70.2	76.0	43.2	0.0	0.0	0.0
6	214.2	221.7	23.1	27.8	54.1	0.0	27.5	0.0
9	82.8	101.0	38.3	68.6	17.8	0.0	15.9	0.0
11	129.1	196.8	58.0	103.2	25.0	0.0	9.1	0.0
14	186.8	213.5	136.6	105.8	0.0	0.0	5.8	0.0
15	296.7	327.4	28.2	98.5	33.9	0.0	0.0	0.0
16	215.6	n/a	141.5	n/a	0.0	n/a	0.0	n/a
17	169.3	217.7	88.1	99.5	16.9	0.0	0.0	0.0
18	159.0	175.7	107.3	69.0	16.4	0.0	0.0	0.0
19	135.5	164.6	61.4	41.8	3.5	0.0	0.0	0.0
20	288.8	n/a	50.8	n/a	0.0	n/a	0.0	n/a
21	319.8	321.9	117.6	97.6	46.5	0.0	27.8	0.0
22	185.2	191.0	48.9	13.0	0.0	0.0	0.0	0.0
23	287.7	268.8	20.8	37.0	4.1	0.0	0.0	0.0
24	179.7	n/a	74.8	n/a	18.0	n/a	19.5	n/a
25	132.0	n/a	14.1	n/a	12.4	n/a	1.3	n/a
26	95.7	115.6	57.1	77.9	20.1	0.0	0.0	0.0
27	214.5	232.5	15.8	57.1	19.7	0.0	0.0	0.0
28	238.3	269.4	12.5	35.4	0.0	0.0	9.4	0.0
29	39.7	62.6	11.0	21.4	8.4	0.0	0.8	0.0
30	132.9	n/a	20.1	n/a	4.6	n/a	1.9	n/a
31	292.5	268.4	193.3	26.9	22.7	0.0	0.0	0.0
32	378.8	n/a	40.7	n/a	8.9	n/a	4.6	n/a

[1] Spruce beetle-attack category definitions (Shore 1985) in Appendix 1.

Table 8b. Volume of overstorey white spruce by dead spruce beetle attack categories: grey, partial, pitch-out, and dead by causes other than spruce beetle.

Volume (m^3/ha) by Spruce Beetle-attack Category

	Grey		**Partial**		**Pitch-out**		**Dead**	
Plot No.	**2000/2002**	**2010**	**2000/2002**	**2010**	**2000/2002**	**2010**	**2000/2002**	**2010**
1	38.4	170.6	34.8	20.1	0.0	0.0	19.5	19.0
2	3.1	55.9	0.0	15.8	0.0	0.0	0.0	11.8
3	128.5	216.2	0.0	2.9	0.0	0.0	0.0	0.0
4	34.0	89.4	0.0	9.8	0.0	0.0	0.0	8.5
5	132.2	195.1	38.9	4.6	0.0	0.0	0.0	1.6
6	98.6	168.1	10.9	22.9	0.0	0.0	0.0	2.9
9	8.8	32.4	2.0	0.0	0.0	0.0	0.0	0.0
11	15.7	57.0	20.7	19.9	0.0	0.0	0.6	16.8
14	42.1	53.0	0.0	54.7	0.0	0.0	2.3	0.0
15	175.5	190.3	48.1	38.7	0.0	0.0	11.0	0.0
16	71.4	n/a	2.7	n/a	0.0	n/a	0.0	n/a
17	62.7	75.3	1.6	6.5	0.0	2.0	0.0	34.4
18	28.5	77.3	6.8	27.9	0.0	0.0	0.0	1.5
19	57.4	73.1	2.0	22.5	0.0	0.0	11.2	27.2
20	220.9	n/a	0.0	n/a	0.0	n/a	17.1	n/a
21	81.4	185.9	38.7	28.5	0.0	0.0	7.8	9.9
22	117.0	151.7	19.3	26.2	0.0	0.0	0.0	0.0
23	183.3	177.1	0.0	54.7	71.7	0.0	7.8	0.0
24	45.3	n/a	14.0	n/a	8.0	n/a	0.0	n/a
25	65.6	n/a	15.7	n/a	22.9	n/a	0.0	n/a
26	6.9	35.0	10.8	2.7	0.8	0.0	0.0	0.0
27	143.3	151.7	0.0	23.7	35.6	0.0	0.0	0.0
28	196.1	222.3	0.0	11.7	15.4	0.0	4.8	0.0
29	0.0	39.1	6.6	1.3	12.0	0.0	0.8	0.9
30	106.2	n/a	0.0	n/a	0.0	n/a	0.0	n/a
31	16.8	120.6	0.0	120.9	0.0	0.0	59.8	0.0
32	277.4	n/a	3.5	n/a	12.9	n/a	30.7	n/a

[1] Spruce beetle-attack category definitions (Shore 1985) in Appendix 1.

3.6 Growth and Establishment of White Spruce Overstorey: Understorey, Advanced Regeneration, and Seedlings

Of the eight white spruce ARSTAN chronologies, plots 4, 6, 11, and 28 share a common deviation from the ring-width index mean of 1.00 after 2000 (Figure 12). Plots 4, 6, and 28 display the most prominent deviations from the mean. The remaining plots 2, 5, 14, 19 are approaching the mean of 1.00. Of these, plots 5, 14, and 19 are the oldest chronologies.

Based on a two-factor extraction, 65.6% of the total variance can be explained across all eight ARSTAN chronologies, where Factors 1 and 2 explain 42.9% and 22.7% respectively. The general trend line between the two factors indicates an inverse relationship. Factor 2 index values spike significantly in 1998, whereas Factor 1 exhibits a 4-year lag and begins a moderate slope increase in 2002. In addition, Factor 1 has distinguishably higher index values corresponding with the time frame 1930–1952. (Figure 13).

Factor loadings are given in Table 9 and illustrate which plot groupings correspond best to factor loading values. Factor 1 groupings include plots 2, 5, 14, 11, and 19. Factor 2 groupings include plots 6, 28, and 4. All significant loading values are in bold.

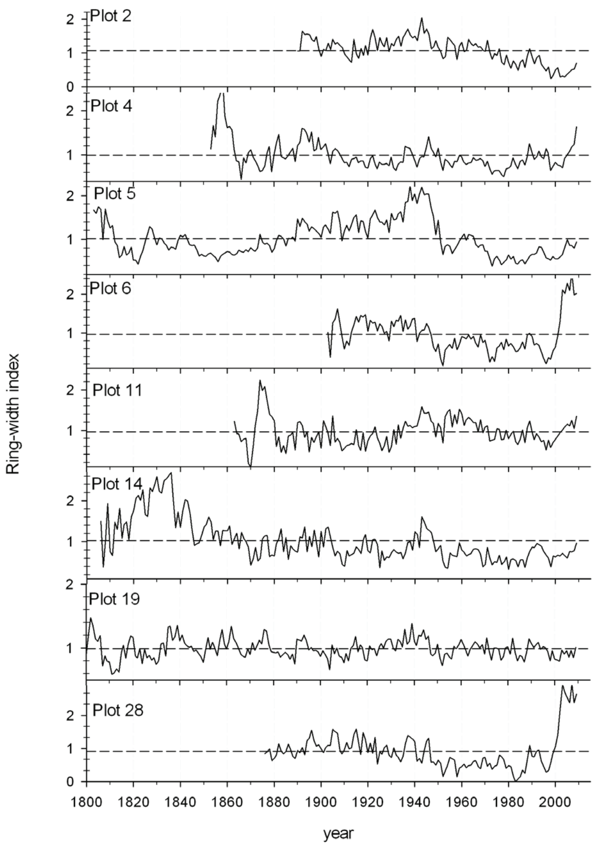


Figure 12. Master ARSTAN chronologies for eight white spruce dendrochronology plots (1800–2009) in the southwest Yukon.

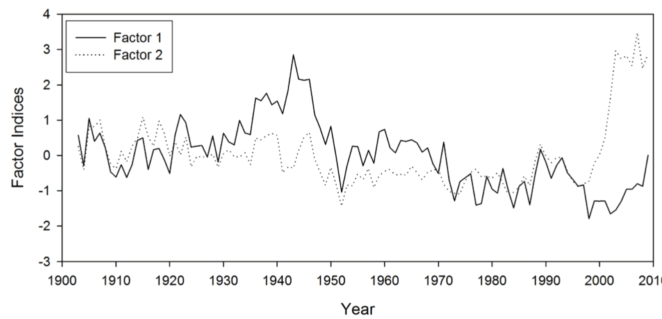


Figure 13. Factor analysis chronologies for the eight dendrochronology plots.

Table 9. Factor loadings for the eight dendrochronology plots (significant values in bold).

Factor 1		Factor 2	
Plot Groupings	Factor Loadings	Plot Groupings	Factor Loadings
2	**0.87**	6	**0.91**
5	**0.81**	28	**0.96**
14	**0.71**	4	0.56
19	**0.73**		
11	0.56		

Overstorey white spruce in the Factor 2 plot groupings show a strong growth release since the start of the spruce beetle outbreak in the mid-1990s while Factor 1 plot groupings show a lag in growth release until 2002, but then show a moderate release to 2009.

Live overstorey white spruce date from 1740 to 1910 (Figure 14). Two percent of the live overstorey white spruce were 270 years old (established in 1740). The highest percentage of live white spruce were established in 1870, 1880, and 1830 representing 11%, 11%, and 9% of the total number of trees. The average white spruce age for all plots was 170 years, which represents an establishment year of 1839. Significant variations in establishment ages were found across all plots ($p = 0.000$, Kruskal-Wallis test) (Figure 15). Plots 5, 14, and 19 show the greatest deviation from the regional mean establishment date with means of 1781, 1807, and 1807, respectively.

White spruce understorey (≥1.3 m height <10 cm DBH) establishment covered a period of 180 years (1780 to 1960). The oldest understorey mean ages and the highest variability occurred in plots 4, 5, and 19 (Figure 15). Fifty-three percent of the understorey samples were established between 1920 and 1940 (Figure 14). Significant variations in mean establishment dates were not found at the plot level ($p = 0.000$, Kruskal-Wallis test). Plot 19 contained the most variation in establishment dates including the oldest understorey tree dating back to 1783 (Figure 15).

Advanced regeneration (≥10 cm <1.3 m height) were established between 1920 and 2000 (Figure 14). The mean establishment age was 40 years with an establishment year of 1969. Of the plots sampled, the highest percentage of advanced regeneration was from the 1980s (Figure 14). The 1980 establishment pulse was best represented in plots 4, 6, 11, and 19. The next largest groups of samples were from the 1960s and 1970s, both at 15%, and the 1990s at 14%. The box and whisker plot for plot 2 (Figure 15) illustrates a significant deviation in establishment age from the remaining seven plots. The Kruskal-Wallis test of variation indicated significant differences in mean establishment dates ($p = 0.004$) at the plot level for advanced regeneration.

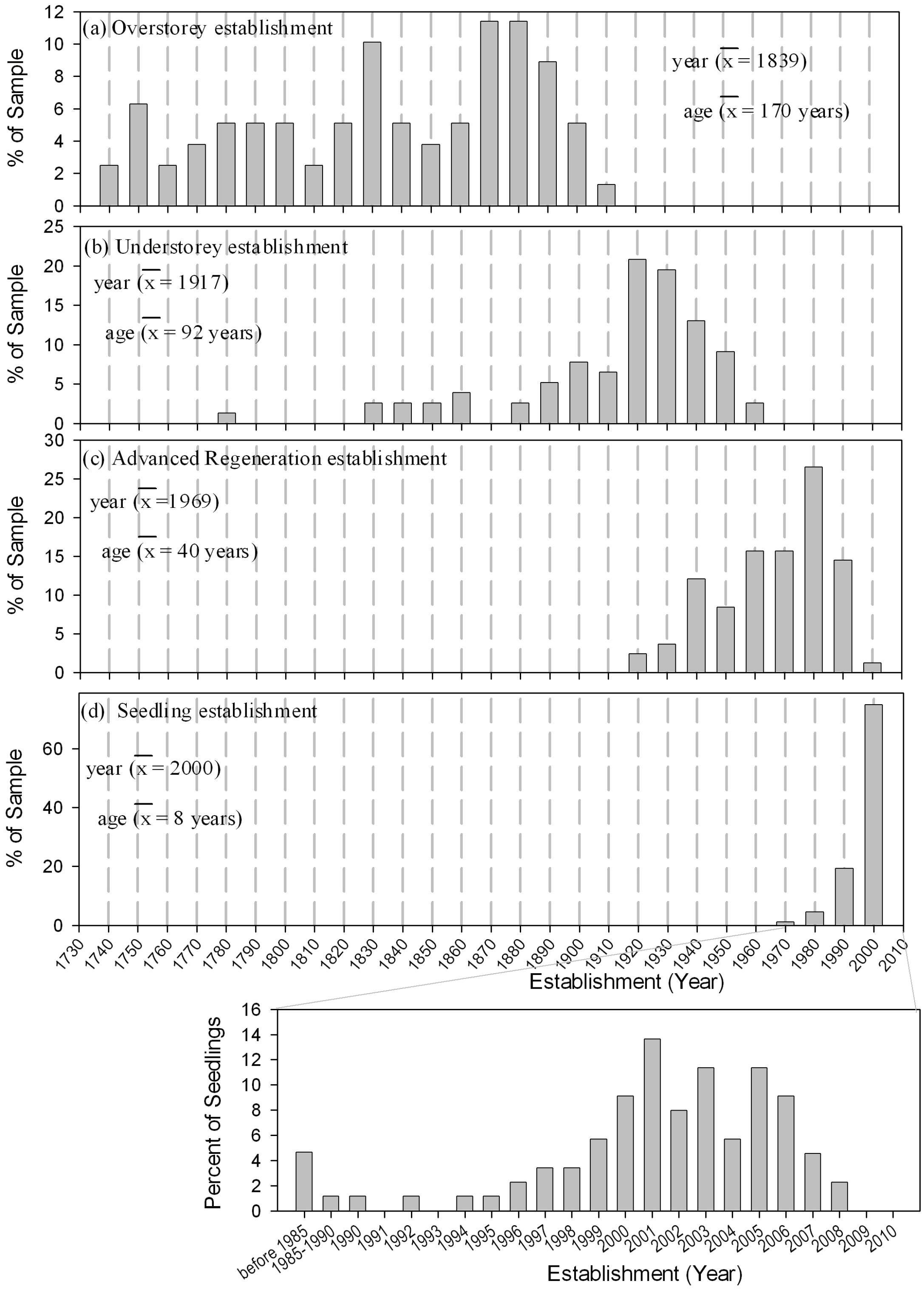


Figure 14. Establishment dates for a) overstorey (≥10 cm DBH), b) understorey (≥1.3 m height <10 cm DBH), c) advanced regeneration (≥10 cm <1.3 m height), and d) seedlings (<10 cm height).

Seedling establishment (<10 cm height) dates spanned four decades with the oldest seedling dating to 1977. Over 59% of the seedlings were established between 2000 and 2008 (Figure 14). The highest percentage of seedlings established in a single year was 14% in 2001 (Figure 14). The box and whisker plot for Plot 19 (Figure 15) illustrates a significant deviation in establishment age from the other seven plots. At the plot level, significant differences in mean establishment dates were found ($p = 0.000$) using a Kruskal-Wallis test.

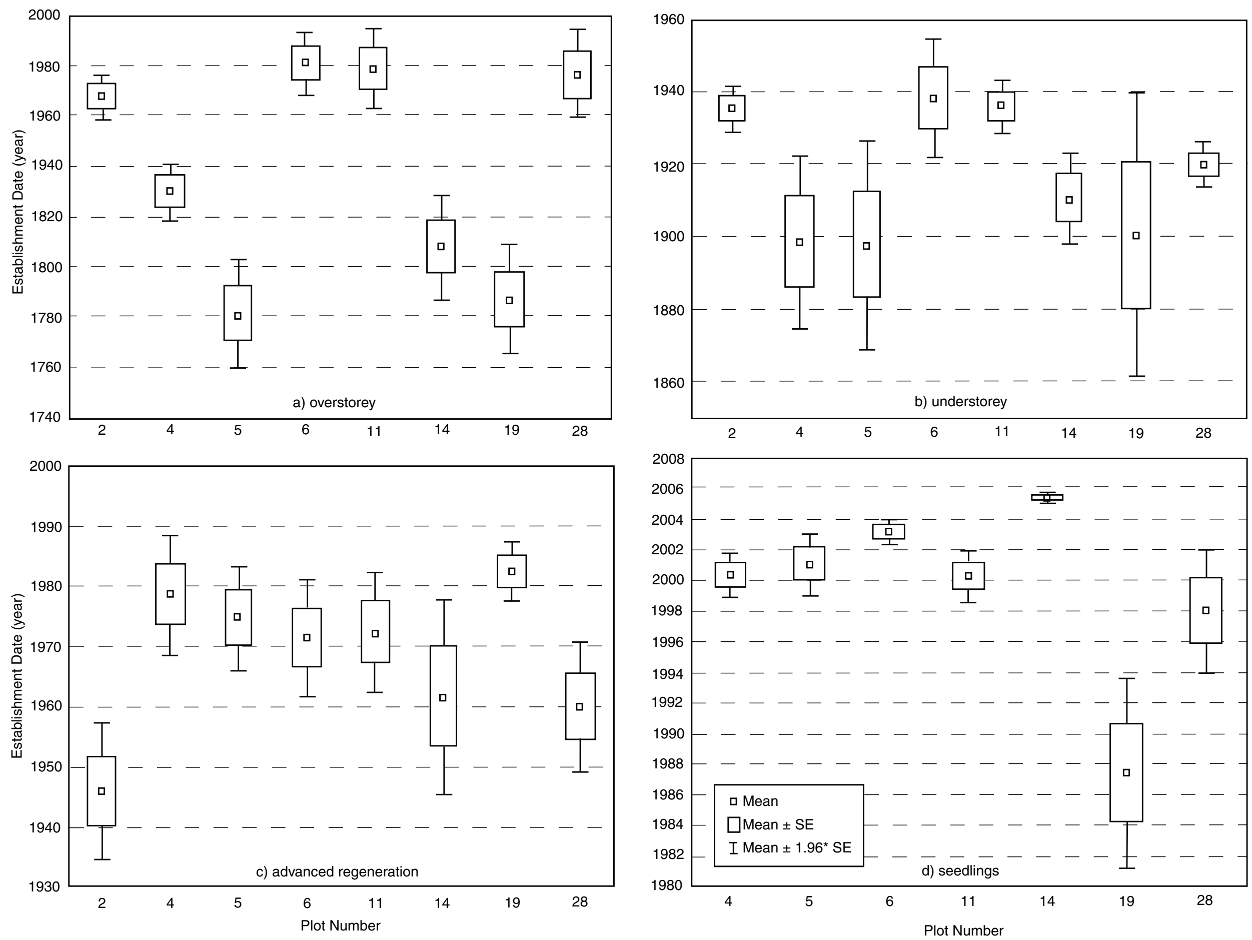


Figure 15. Box and whisker plots showing variation in establishment dates of white spruce across eight plots in southwest Yukon for a) overstorey (> 10 cm DBH), b) understorey (> 1.3 m height < 10 cm DBH), c) advanced regeneration (> 10 cm < 1.3 m height), and d) seedlings (< 10 cm height).

4. Discussion

Garbutt et al. (2006) recommended that the first complete re-measurement should occur when a significant proportion of the dead spruce branchlets had been shed or enough dead spruce had fallen to increase light penetration and stimulate growth of the understorey spruce (saplings and seedlings). The 2010 partial re-assessment provided, in a more quantitative manner, the degree of change in overstorey white spruce and deciduous species stand characteristics (e.g., density and volume by tree status) and whether these changes were enough to encourage growth of the remaining live overstorey and understorey spruce as well as stimulate spruce seedling establishment.

There is an increased interest in using bioenergy to reduce the consumption of high-cost, refined petroleum products and associated emissions in the Yukon (PBrand Bioenergy Consulting 2009). As a result, pressure to harvest trees might increase in the spruce-beetle impacted area in southwest Yukon, which could increase the likelihood of the FA plots being impacted. Thus, the need to develop buffers to protect them for future re-measurement is beneficial. The FA plot priority rating will be useful to determine which plots should be buffered immediately.

Although there was no change in the "dead tree" component of the fire hazard rating system, the increase in spot fire potential is important to fire managers in the Yukon. Beaver (1997) developed a fire behaviour case study for fire HJ-03-97 that occurred northeast of Haines Junction in spruce-beetle impacted forest. The wildfire, under moderate fire danger conditions, exhibited high fire intensity and spotting (up to 800 m) demonstrating present and future fire hazards, which can be expected from beetle-impacted stands and are a challenge for fire suppression. The increase in spot fire potential, based on changes in the percentage of loose bark on dead spruce, indicates that fire suppression may be more difficult where there is significant mortality of white spruce (Figure 10). Alexander and Stam (2003) produced a safety alert for wildland firefighters in relation to fuel conditions in spruce-beetle killed forests of Alaska. The authors indicated that prolific fire spotting and the potential for "mass fire" or area ignition are usual in spruce-beetle-killed areas.

There was no increase in average coarse woody debris (> 7 cm diameter) across all re-measured plots from 2000/2002 to 2010 indicating no significant fall-down of beetle-killed white spruce has occurred. Half of the re-measured plots did have an increase in coarse woody debris loading. Some fall-down is starting to occur and will accelerate in the next few years (Figure 16). In a Lutz spruce (*Picea lutzii* Little) forest on the Kenai Peninsula, Alaska, 50% of the spruce-beetle-killed trees had fallen to the ground after 16 years (Holsten et al. 1995). Schulz (2003) reported that 13 years after a spruce beetle outbreak on the Kenai Peninsula, there was an increase in coarse woody debris of 6.8 t/ha (> 7.6 cm). Fall-down of spruce-beetle killed spruce will take longer as the climate of southwest Yukon is much drier than the Kenai Peninsula in Alaska. Werner et al. (2006) reported that white spruce killed by spruce beetles in the cool and dry climate of the Copper River Basin, Alaska remained standing for more than 50 years following a 1930s outbreak.

Growth release between 2000 and 2010 was detected in live overstorey spruce trees that survived the recent spruce beetle outbreak. Two of the eight plots (6 and 28) sampled were grouped by a factor analysis showing a significant growth release (Factor 2, Table 9). The sampled overstorey trees in these two plots had the youngest mean stand age along with plot 11. The older spruce, especially in plots 5, 14, and 19, may have not been able to respond immediately to increased light and soil moisture. Schulz (1996) indicated that residual spruce trees in Alaska could have accelerated growth after a spruce beetle infestation because of an increase in available site resources. Veblen et al. (1991) reported there were increases in the percentage of spruce trees released

Figure 16. Significant fall-down of spruce-beetle-killed spruce on plot 18 west of Dezadeash Lake.

as a result of a beetle outbreak in the 1940s and 1950s in Colorado. The pre-attack health and vigour of a spruce stand may influence the ability of surviving live spruce to increase their growth rate post-attack perhaps leading to older spruce stands taking longer to respond than younger ones. An increase in soil nutrients, moisture, and understorey light levels may take longer to occur in southwest Yukon as compared to the Kenai Pennisula in Alaska because of the dry and cold climate of southwest Yukon where decomposition is slow and dead spruce are not quick to shed their branchlets or fall down. Lindgren and Lewis (1997) documented an increase in white spruce growth rates starting in the early 1820s and extending into the 1860s in the McGregor River area northeast of Prince George. This might have been the result of a spruce beetle outbreak, but the dendrochronological evidence of an outbreak was not clear, possibly due to the open and uneven stand structure. It may also be the reason why the Berg et al. (2006) study of past outbreaks in southwest Yukon could not detect outbreaks prior to the 1930s–1940s.

Understorey establishment dates indicated that white spruce has regenerated over a period of 180 years across all plots with a pulse from 1920–1940. Advanced regeneration establishment dates indicated that the 1980s were a significant period of spruce regeneration, especially in plots 6, 19, 4, and 11. Over 70% of the seedlings measured were established between 2000 and 2010. This trend was particularly pronounced in the period from 2000 to 2008. Pulses of understorey, advanced regeneration, and seedlings may be indicative of past canopy disturbances, abundant summer rainfall, large cone crops (can increase spruce germinate survival), and suitable seedbeds (DeRose and Long 2010). Although there was a spruce beetle outbreak in the southern part of the study area during the 1930s and 1940s, the bulk of the plots lie outside this outbreak area. Only plot 2 was found to have a regeneration pulse in the 1940s. Plots 5, 6, 11, 14, and 19 understorey establishment dates reflect continuous regeneration over a long period of time. Werner et al. (2006) reported that short viability of seed in soil, long return intervals for mast cone crops, vegetation competition, and poor seedbed conditions limit Lutz and white spruce seedling establishment in Alaska. Holsten et al. (1995) described what commonly follows a spruce beetle outbreak in Alaska as involving understorey tree, shrub, and herbaceous vegetation release and the lack of spruce seedling establishment.

Although there are pulses in the establishment of spruce seedlings, spruce were recruited continuously in the plots sampled. Continuous spruce recruitment was also described by Veblen (1994) in the US Rocky Mountains where small canopy openings and new seed beds are continually created by windthrow. The white spruce stands sampled in southwest Yukon have reached a late seral stage, after an initial stand replacing event like fire or lake draining (Alsek River valley), where gap dynamics play a significant role in creating small openings and seed beds suitable for spruce regeneration (DeRose and Long 2010; Turner et al. 2001) (Figure 17). Recruitment after wildfire in southwest Yukon was studied by

Figure 17. Windthrow on plot 14 has created a mineral soil seed bed where some white spruce seedlings have established.

Zalatan (2002) and his research showed that white spruce regeneration peaked 20–40 years after fire and then decreased. van Hees (2005) assessed white spruce seedling (< 2.54 cm DBH and rooted in mineral soil) density after a spruce beetle outbreak on the Kenai Peninsula, Alaska. The study found that only 20% of the plots had five or more seedlings, considered adequate for full stocking.

Climate change will be especially important to consider in future research of spruce beetle impacts in boreal forests as higher latitudes are projected to experience the greatest temperature increases (Soja et al. 2007), perpetuating host susceptibility due to drought and beetle survivorship. Chavardès et al. (2012a) used dendrochronology to determine climatic variation effects on white spruce radial growth in southwest Yukon. They found that white spruce trees were not stressed by drought when the current spruce beetle outbreak started 1994 and during the next 14 years of the outbreak. This seemed to suggest that the current outbreak was the result of climate effects on beetle population dynamics rather than by drought-induced stress reducing spruce vigour and increasing beetle susceptibility. The two documented spruce beetle outbreaks in southwest Yukon in the 1930s–1940s and 1994–2008 are a recent 20th century phenomenon (Berg et al 2006). Chavardès et al. (2012b) found that climate change projections included further temperature and precipitation increases that may continue to increase tree growth although seasonality and interactions between temperature and precipitation could affect tree growth response in an unforeseen way.

Southwest Yukon is an excellent study area for monitoring the effects of the current spruce beetle outbreak, and future disturbances, such as climate change, possibly increase the risk of spruce beetle outbreaks and wildfires. The ecosystems of southwest Yukon may experience very rapid shifts in disturbance regimes and respond on several tropic levels, perhaps creating a new stable state (Andersen et al. 2008).

There is a strong interest in maintaining these FA plots by forest health and fire research staff and management at Pacific Forestry Centre and Government of Yukon fire and forest management agencies. Canadian Forest Service research scientists working on disturbance dynamics and insect impacts in northern Canada are interested in these long-term plots. These plots need to be protected from future human disturbance, and the data collected from them archived and maintained by the Canadian Forest Service. The results of the 2010 re-assessment indicate that a complete re-measurement of the long-term spruce beetle monitoring plots should be considered starting in 2015. The complete re-measurement should consider including all attributes measured in Garbutt et al. (2006) and in the 2010 re-measurement.

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Appendix 1. Yukon Plot Code Sheets

All Yukon plot code sheets except for the bark beetle attack status code were taken from *Canada's National Forest Inventory ground sampling guidelines: Specifications for ongoing measurement* (CFIC 2008). The bark beetle (BB) attack status code sheet was taken from Spruce Beetle and the Forests of the Southwest Yukon (Garbutt et al. 2006).

Tree Status Codes: Record the tree status code that best describes the live or dead large tree. Note that dead fallen trees are not collected in the Large Tree Plot.

Tree Status	Code	Description
Live Standing	LS	Live trees that are self-supporting (i.e., the tree would remain standing if all supporting materials were removed).
Live Fallen	LF	Live trees that are not self-supporting (i.e., the tree would not remain standing if all supporting materials were removed).
Dead Standing	DS	Dead trees that are self-supporting (i.e., the tree would remain standing if all supporting materials were removed).

Dominance Class: Crown class is a ranking by crown position of a tree in relation to other trees in the immediate area surrounding the tree being measured. The crown class is used in the selection of site trees on the plot.

Dominance Class Codes

Crown Class	Code	Description
Dominant	(1) D	Trees with crowns that extend above the general level of the trees immediately around the measured trees. They are somewhat taller than the co-dominant trees, and have well-developed crowns, which may be somewhat crowded on the sides, receiving full light from above and partly from the side.
Co-dominant	(2) C	Trees with crowns forming the general level of the trees immediately around the measured trees. The crown is generally smaller than those of the dominant trees and is usually more crowded on the sides, receiving full light from above and little from the sides.
Intermediate	(3) I	Trees with crowns below, but extending into, the general level of the crown canopy (may include trees, shrubs, or other obstructions) immediately around the measured trees. The crowns are usually small and quite crowded on the sides, receiving little direct light from above, but none from the sides.
Suppressed	(4) S	Trees with crowns entirely below the general level of the crown canopy (may include trees, shrubs, or other obstructions) around the measured trees, receiving no direct light either from above or from the sides.
Veteran	(5) V	Mature trees that are considerably older than the rest of the stand. Usually, veterans are trees remaining from a previous forest that have survived while a new forest has been growing up around them. Different jurisdictions will have different age thresholds for the age at which a tree becomes a veteran (Dunster and Dunster 1996).
Not Applicable	(6) N	Trees where the crown class measurement is not applicable (e.g., trees with a broken top resulting in a missing or minimally effective crown; standing dead trees; or fallen live trees).

BB (Attack Status): Spruce beetle-attack status recorded for each tree (Shore 1985).

Attack Status	Code	Description
Healthy	H	Unattacked; includes deciduous trees.
Current	C	Attacked and killed in the current year.
Red	R	Attacked and killed in the previous year.
Grey	G	Attacked and killed two or more years previously.
Partial	P	Either currently or previously attacked, but not killed.
Pitch-out	PO	Beetle attacks overcome by tree's defensive resin flow.
Dead	D	By causes other than spruce beetle.

Stem Condition: Use this field to indicate whether the main stem of the tree is intact (I) or broken (B).

Crown Condition: Examine the crown in relation to a normal live crown (lower crown loss due to self-pruning is not included). Record the appropriate code (1 to 6).

Crown Condition Codes

Code	Description
1	All foliage, twigs, and branches present.
2	Some or all foliage lost, possibly some twigs lost, all branches usually present.
3	No foliage, up to 50% of twigs lost, most branches present.
4	No foliage or twigs, up to 50% of branches lost.
5	No foliage or twigs. Some sound and rotting branch stubs may be present.
6	No foliage, twigs, branches, or branch stubs.

Bark Retention: Record the bark retention code that best describes the proportion of bark remaining on the tree.

Bark Retention Codes

Code	Description
1	All bark present.
2	Bark lost on damaged areas only (< 5% lost).
3	Most bark present, bare patches, some bark may be loose (5–25% lost).
4	Bare sections, firm and loose bark remains (26–50% lost).
5	Most bark gone, firm and loose bark remains (51–75% lost).
6	Trace of bark remains (76–99% lost).
7	No bark (100% lost).

Woody Debris and Stump Decay Class Descriptions

	Decay Class				
	1	2	3	4	5
Wood Texture	intact, hard	intact, hard to partly decaying	hard, large pieces partly decaying	small, blocky pieces	many small pieces, soft portions
Portion on Ground	elevated on support points	elevated, but sagging slightly	sagging near ground, or broken	all of log on ground, sinking	all of log on ground, partly sunken
Twigs <3 cm length (if originally present)	twigs present	no twigs	no twigs	no twigs	no twigs
Bark	bark intact	intact or partly missing	trace bark	no bark	no bark
Shape	round	round	round	round to oval	oval
Invading Roots	none	none	in sapwood	in heartwood	in heartwood

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